University of Pittsburgh

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Special Notice

This report, due on 1 November 1965, was not submitted until 18 April 1966. It does, however, represent the state of progress as of that earlier date because reports were collected from several investigators in October, 1965.

I. Introduction

1. The SRCC: The Space Research Coordination Center identifies three phases of its development:

Phase I	Broad-based build-up of basic competence in science	Completed
Phase II	Broad-based build-up of basic competence in engineering	Starting
Phase III	Sharper emphasis on space-oriented research	Under way

2. SRCC Reports: The Space Research Coordination Center adopted in April, 1965, the practice of distributing SRCC research reports. These are largely preprints of manuscripts submitted for publication or reprints of published papers. The criteria of Phase III are used in selecting these reports, a list of which appears in Section V.

3. SRCC Building: The space-oriented research programs at the University of Pittsburgh were greatly strengthened by the recent completion of the NASA-financed (Facilities Grant NsG(F)-13) SRCC building, which was dedicated on 18 November 1965. The building is now fully occupied by an interdisciplinary team made up of physicists, chemists, engineers and earth scientists and by the KAS Center.

At the beginning of Phase I, funds from NASA Research Grant NsG-416 were used to initiate carefully selected research programs for new faculty members appointed under SRCC auspices in the Division of the Natural Sciences. These programs are now largely supported by project grants, from NASA and from other sources. The NASA institutional grant made it possible for these new programs to come into being.

As Phase II starts, substantial funds from the NASA grant are being diverted to the School of Engineering to initiate new research programs by the present faculty and by new faculty members appointed (and to be appointed) under SRCC auspices. None of these programs are as yet far enough along so that publication is imminent.

Under Phase III, funds from the NASA grant and from local sources are made available for the initial support of new programs, either by the present faculty or by newly appointed faculty members, and for an expanded program of postdoctoral study. In choosing among applications for support, special emphasis will be given to the space-orientated character of the proposed projects.

II. Project Reports--Division of the Natural Sciences

1. Atomic and Plasma Physics Laboratory (Professor M. A. Biondi, Dr. L. Frommhold and C. S. Weller)

a. Recombination of Ionospheric Ions--Two research programs, largely supported by ARO (Durham), are aimed at determining in the laboratory the recombination coefficients for electrons with ions which occur in the ionospheric region from 60-400 km above the earth. In the first experiment microwaves and mass spectrometric techniques are used to study photoionized NO plasma-afterglows to determine recombination between NO^+ ions and electrons at 300°K. These studies are being carried out, in part, by C. S. Weller, NASA Predoctoral Fellow.

The second experiment involves use of microwave heating of electrons in afterglows to determine the energy dependences of recombination coefficients under ionospheric conditions. Thus, the ion temperature is in the range 200-400°K while the electron temperature can be raised from these values upwards (>2000°K). These studies are being carried out, in part, by Dr. L. Frommhold, NASA Postdoctoral Fellow.

b. Radiation Transport in Plasmas--The transport of resonance radiation through ionized mediums is being studied for the case of cesium resonance radiation in partially ionized cesium vapor [under the support of ARO (Durham)]. Photoelectric recording Fabry-Perot interferometry is being used to observe the transmitted spectral line shapes in order to compare with theoretical predictions involving doppler, natural, and plasma broadening of the spectral lines. These studies are of interest in connection with similar radiation transport

problems in astrophysical observations. The work has, in part, been carried out by F. Ullrich while a NASA Predoctoral Fellow.

c. In continuation of our studies on dissociative recombination, an attempt has been made to study line shapes of many different spectral lines in Neon and Argon in a microwave afterglow. Although the preceeding investigation of Biondi and Connor was principally successful in the sense of having established the proof that dissociative recombination is the prevailing process, it seemed worthwhile to extend that study of a single Neon line (5852Å) to other spectral lines, as well as to other gases as Argon. In a qualitative sense, this new study confirmed the conclusions obtained in Neon, and demonstrated the importance of the dissociative recombination process in Argon, too. Quantitatively, however, different lines of the same gas did not lead to comparable results (as: energy of dissociation of the molecular ion), which definitively disagreed. As a careful study showed, the afterglow lines exhibit an unexpected "fine structure." The work is not yet finished, though the conclusion seems unavoidable that the molecular ions are in vibrationally excited states (with differing values of the apparent binding energy). This assumption would certainly explain both observations, thus giving an unexpected additional proof for the importance of molecular ions in the two-body recombination process, and, hopefully, some new information on the properties of molecular rare gas ions, as: vibrational frequencies and (real) binding energies.

Besides this line shape study, some effort has been made to set up a new apparatus for determining recombination rates at controlled

electron temperatures. Over a wide range of energies, electron temperatures during the afterglow can be controlled only by electric fields of a controlled strength. Thus, a multimode cavity has been set up which is highly resonant (Q = 10,000) in some of the used modes, and perfectly non-resonant (like a infinite wave guide) in another mode. This enables one to measure plasma densities (and their decay during the afterglow phase) by the detuning effect of the electrons, and, at the same time, control their energy independently from the actual value of the electron density. The entire microwave system has been checked out, and the apparatus hopefully will be in a working condition soon.

Both activities have been supported by AROD 31-124-G-518.

2. Atomic Beam Group (Professors W. L. Fite and R. T. Brackmann, Drs. W. R. Henderson and J. E. Mentall, Messrs. W. R. Ott, L. M. Clendenning, H.-H. Lo, W. E. Kauppila and J. A. Kossey)

a. Hydrogen Atom Research--The past six months have seen the completion of the basic three-stage modulated beam machine for studying collisions between charged particles and hydrogen atoms. The machine is currently in use to examine reflection of gases from surfaces, primarily to give us the design information needed to finish the fourth stage of this machine. It is hoped that a suitable gettering material can be quickly found to replace the cryogenic pumping originally planned for the machine. If, for example, liquid-nitrogen-cooler evaporated titanium can be used to trap background gases with an efficiency in excess of 50 per cent, the entire series of experiments on atomic hydrogen can be carried out both at reduced cost and with increased flexibility. These experiments should be

concluded shortly and then the fourth chamber will be built according to the findings. The research is sponsored by NSF.

b. Electron Collisions with Excited Molecules--The dissociative attachment of electrons to O_2 heated to about 2000°K changes markedly for reasons which seem to be incompatible with our understanding of molecular processes. Studies of signal as a function of temperature at fixed electron energy indicate that electronic and vibrational excitation are probably not the cause of the high rate of O^- formation observed. Similarly, these studies have revealed apparent activation energies too low to allow the process to go on the basis of conservation of energy using the known states. It would seem that either something entirely new in atomic processes is involved, or internally excited O_2 can lead to a new state of O^- with a very high affinity. Attention has been directed toward understanding the very unusual results of earlier measurements using mass spectrometric detection, the first step being to use a total ion collector. With the conservation of energy problem becoming even more marked with the total ion collector, we tend to favor the idea that there may in fact be a high affinity state of O^- not yet identified. If true, this would have very far-reaching consequences with regard to upper atmospheric processes. Efforts to improve the experiments to where they will give unequivocal results are currently receiving the highest priority in the lab. Dr. Watson R. Henderson is carrying the bulk of the experimental measurement work on equipment provided under the SRCC grants. This research is sponsored by DASA through ARO.

c. Neutral-Neutral Airglow Reactions--The modulated beam machine for the pursuance of experiments to study a number of free

radical reactions suspected of being responsible for airglow excitation is nearing completion. Presently the oven source for producing sodium and NaO (hopefully) is under construction. It is anticipated that it will shortly be under test and that within the next six months studies of reactions leading to sodium D-line excitation will be under way. These experiments are being supported by NASA and are being carried on by Dr. J. E. Mentall and graduate students.

d. Helium Loss Processes--As parts of the two modulated beam machines were completed, they were used as vacuum chambers for an experiment to study methods for detection of neutral products of ion-neutral reactions. Basically a very simple double-electron-gun mass spectrometer, this experiment was used to attempt to confirm or deny the contention that He^+ reacts with atmospheric molecules through the formation of ionic complexes as opposed to dissociative charge transfer. If complex formation is involved, then the neutral helium could be formed with energies sufficient to escape from the earth's gravitational field; if dissociative charge transfer, the He would be formed with energy inadequate to escape. The facts that He does apparently escape from the earth at a rate approximately equal to the photoionization rate suggests that ion reactions may be responsible. The hope of this experiment was to settle the question and identify the reaction once and for all, or failing this, to give experience in detecting very small amounts of fast neutral reaction products and thereby teach us how to build the experiment properly. To date the experiment has done more of the latter than of the former. Because of the demands of the sponsored programs, this experiment will be temporarily set aside. This experiment is unsponsored.

e. Heavy Ion Exchange Collisions--In the early portions of the past six months, measurements were made on the charge changing cross sections for Fe^+ and U^+ in atmospheric gases. Following these measurements the program has been suspended temporarily during the move to the new SRCC building. Presently we are awaiting delivery of a 2 Mev Van de Graaff accelerator which is being supplied by the sponsors, and then the program will be resumed. Aimed at measuring cross sections relevant to questions of deposition of atomic weapons debris the program is also among the first to set the patterns for electron capture and loss cross sections for heavy ions other than those of the inert gases. The research is supported as a subcontract of a prime contract awarded to General Atomic by the Air Force Weapons Laboratory. Professor Brackmann is in charge of the measurements.

In addition to Professors Fite and Brackmann and Doctors Henderson and Mentall, four graduate students (William R. Ott, Lester M. Clendenning, Hsi-Hu Lo, and Walter Kauppila) and one undergraduate student (John Kossey) are participating in these research activities.

3. Scattering Theory (Professor E. Gerjuoy, Drs. L. Hostler and G. Nutt)

a. The paper "Electron-Atom and Electron-Molecule Scattering Theory Circa 1964" which was mentioned in the last Semi-Annual Report has been published in Physics Today, Volume 18. The paper, "Momentum Transfer Theorem for Inelastic Processes," also mentioned in the last Semi-Annual Report, has been published in the Journal of Mathematical Physics, Volume 6. In addition a meeting report, "Momentum Transfer Theorem for Inelastic Processes" (with W. Fite) has been published in the Journal of Mathematical Physics. Moreover during the summer of

1965 Lavere Hostler, Research Associate in the Department of Physics, working on the subject of electron hydrogen collisions has completed two papers which probably will be published, and which have been issued as SRCC reports. These papers are "The Runge-Lenz Vector and the Coulomb Green's Function," and "Formal Scattering Theory and the Coulomb Problem."

b. In the meantime work continues on various theoretical problems concerned with the calculation of atomic cross sections. The review on the methods of constructing variational principles for arbitrary matrix elements of arbitrary operators still is in preparation. A very intensive effort to calculate charge transfer and other atomic cross sections by so called classical means is under way in cooperation with personnel at the Goddard Space Flight Center, Greenbelt, Maryland. Also the effort to use the Faddaev equation to compute electron hydrogen scattering continues, in collaboration with Dr. Gerald Nutt, Research Associate. As in the past, some of the work described above is supported on outside contracts.

4. Chemical Kinetics (Professor F. Kaufman)

Work was started on three experimental research programs in the general area of chemical kinetics and aeronomy. These are: (1) Formation, identification, and quenching of metastable atomic and molecular species of oxygen and nitrogen; (2) Measurement of radiative lifetimes of excited triatomic molecules; and (3) Experimental studies of the energy dependence of simple atom recombination reactions.

Of these, the first is farthest advanced. It uses vacuum ultraviolet spectrometry as its method of detection and consists of two separate flow systems, one in which metastable species are produced

and pumped in steady flow past the entrance slit of the grating monochromator; and another which constitutes the light source for the radiation to be absorbed by the desired species.

Initial experiments with microwave discharges in flowing nitrogen showed that the metastable atomic states, ^2P and ^2D, could be observed in absorption when the source of excitation was brought very close to the absorption path, but that they were not observable when the source was removed slightly. This indicates that the metastable states are efficiently quenched, either by collisions in the gas phase or at the wall. Treatment of the surface with the usual "poisoning" materials such as phosphoric acid did not modify the rapid decay, which suggests that gas collisions are responsible for the quenching. The installation of a new photomultiplier tube and of optical windows resistant to radiation damage will greatly improve the signal to noise ratio. This work has received partial support from the U. S. Army Research Office-Durham and from the Office of Aerospace Research, USAF.

The second program is in its initial stages. The excited state(s) of NO_2 -important in the interpretation of the air afterglow-- will be studied in fluorescence by modulated excitation at different wavelengths. The radiative lifetime(s) will then be studied by multichannel pulse height analysis of the fluorescent radiation, also with some spectral resolution.

Several components of the large flow system for recombination reaction studies were received, but this investigation which is supported by the National Science Foundation has not yet been seriously started.

5. Excitation and Collision Studies (Professor E. C. Zipf)

An experimental and theoretical program has been established (1) to study the excitation and collisional deactivation of metastable atoms and molecules of aeronomic interest, (2) to measure the radiative lifetime and to study the collisional quenching of a variety of quasi-metastable states as well as normal radiating states in the time range 1 nanosecond to 500 microseconds, (3) to obtain numerical solutions to the non-linear continuity equation that governs the time-dependent behavior of many of the excited atoms that will be studied in these experiments, and (4) to solve by numerical methods the integro-differential equation that determines the time-dependent structure of the upper atmosphere.

a. Theoretical Calculations--Computer programs have been developed to solve non-linear partial differential equations by an implicit method. These programs are being used in two important problem areas.

1. They are used to analyze experimental data (e.g., light intensity measurements made in afterglow experiments) and to obtain values for such quantities as diffusion coefficients, reaction rates, radiative lifetimes, and recombination coefficients by fitting a numerical solution of the appropriate three-dimensional conservation equation to these data by means of a least squares procedure. This method permits data reduction and analysis without resorting to oversimplified models, and in addition, facilitates the rapid treatment of large volumes of data by a digital computer. The existence of this capability is a very important element in the automatic data processing system currently under development in our laboratory.

A numerical analysis of this type was recently applied to laboratory data on the destruction of nitrogen molecules in the metastable $A^3\Sigma_o^+$ state in the afterglow. Many important aspects of the decay of these auroral metastable molecules that heretofore were not amenable to detailed quantitative treatment were completely accounted for by the machine calculation, thereby amply testifying to the usefulness of this approach. These results were reported at the 18th annual Gaseous Electronics Conference (Minneapolis, 1965). The computer programs presently available treat only a limited number of experimental geometries. Less restrictive programs are now being formulated so that a wider range of laboratory problems may be considered.

2. The computer programs developed for the analysis of laboratory data are being used to solve the integro-differential equation that determines the time-dependent structure of the upper atmosphere. In connection with this study, additional programs have been developed to calculate the photoionization rates in the ionosphere for the various atmospheric gases, to construct model atmospheres from the calculated temperature distribution or from an experimental profile, and from these results to calculate the density and altitude distribution of the principal atmospheric ions. These results are being used in the interpretation of auroral and airglow data.

b. Laboratory Atomic and Molecular Collision Studies--A versatile data processing system that will permit time-dependent studies of atomic and molecular collision processes, is currently being installed in our laboratory. This system will make maximum effective use of the IBM 7090 computer operated by the University of Pittsburgh, and has a dynamic range both in time and sensitivity that is limited only by

the current state of the art. The system may be used, for example, to study collision processes occurring on a nanosecond time scale with a resolution of about 0.3 nanoseconds, or by contrast to study the time-dependent behavior of oxygen atoms in the ^1D state in the afterglow by measuring the very feeble radiation emitted by these atoms even though their radiative lifetime is 110 seconds.

The laboratory facility is arranged so that a number of distinct and possibly unrelated experiments can be set up in adjoining laboratory rooms. These experiments will be linked by cable to the central data processing unit and will use this facility on a shared-time basis. Because of the great speed with which the data can be collected and transferred to computer compatible tapes, a large number of experiments may be accommodated virtually simultaneously. In addition, because timing, calibration, and other programming signals can be made to originate from the central system, it will be unnecessary to duplicate many common, electronic components at each experiment site, thereby substantially reducing the cost of individual experiments and simplifing the maintainance problem.

6. Communication by Electrical Stimulation of the Skin
(Professor R. H. Gibson)

a. Equal Loudness Functions--The lengthy experiments recently completed have been analyzed along the four major variables--pulse repetition rate, stimulus duration, electrode size, and bodily location. Manuscripts are in preparation. Results will appear in a later report of this series and are also to be reported at the first International Symposium on Mechanisms of the Skin Senses in March.

b. Electrode Area vs. Circumference as Threshold Determinant--As electrode area is increased, threshold "touch" peak

current is raised, although threshold current density (e.g., peak current per unit area) decreases, which possibly indicates a form of receptor spatial summation. However, the generally accepted notion of peak current and electrode physical area together as current density might be oversimplified as being sufficient to account for threshold.

Two types of electrodes were constructed: solid discs of varying diameter and area (50 mm^2 to 800 mm^2), and annuli (washer-shaped) with the same diameter but different areas. Preliminary results indicate that sensitivity may depend on electrode circumference, and thus on the size of the receptive field stimulated, not simply on the total electrical area of the electrode.

c. Effects of Frequency on Electrical "Touch" Sensitivity--The chief purpose is to determine whether the commonly reported "U-shaped" frequency-intensity function for mechanical vibration represents neural function, or is an artifact of tissue mechanical properties (cf. natural resonance around 250 Hz), and thus is not reproducible with electrical stimuli of different frequencies. The experiment is under way.

d. Effects of Electrode Physical Properties on Electrical "Touch" Sensitivity--Touch sensitivity on several bodily loci is being measured as a function of electrode (1) size, (2) curvature and (3) pressure. Tissue electrical resistance and the linear extent of electrode penetration into the tissue are being recorded at touch threshold to determine further, independently of sensory characteristics, the relation between touch sensitivity and tissue electrical and physical properties.

Preliminary results suggest (1) as electrode pressure increases, the voltage for a given current, thus the peak resistance, decreases;

and (2) as the electrode area quadruples, tissue resistance halves. However, the relation with touch sensitivity is unclear.

7. Theoretical Chemistry (Professor F. O. Ellison)

a. Potential Energy Curves and Other Properties of Diatomic Molecules--Modified Atoms-in-Molecules Theory--development of theory that employs experimental atomic data to predict dissociation, ionization and excitation energies of diatomic molecules, and to explain these and other chemical properties in terms of conventional valence structures (J. Chem. Phys. 43, 3654 (1965)).

b. Potential Energy Surfaces for Polyatomic Systems--Diatomics-in-Molecules Theory--a valence theory which utilizes known properties of diatomics to predict structure and stability of small polyatomic molecules, radicals and ions in ground and excited states (J. Am. Chem. Soc. 85, 3540 (1963)). Activation energies of simple reactions may also be calculated. The systems Li_3^+ (J. Chem. Phys. 43, 3405 (1965)), H_4^+, H_5^+ and H_6^+ have recently been studied. Mrs. R. B. Abrams (NASA graduate trainee) is studying ground and excited state potential energy surfaces for BH_2, CH_2, NH_2, for the four-center $H_2 + H_2^* = 2H^*H$ reaction, and for the systems H_5 and H_6. F. O. E. has started study of the $O + O_2$ exchange reaction.

c. Short-range Interactions in Systems AH_n--A semiempirical united atom model for estimating potential energy curves of diatomic hydrides has been developed and is described in a paper now being written. Further refinement and extension to polyatomic systems (one heavy atom plus two or more hydrogen atoms) is planned. Very short-range interactions should be accurately predictable by this approach.

d. Long-range Forces--A theoretical study of long-range forces operating between small molecules (in particular, H_2O molecules), especially those forces which are important at high temperatures, is being initiated (in collaboration with Professor Henry Frank).

e. Ab initio Calculations--It is planned to develop (or obtain from other centers) subroutines and programs for carrying out various kinds of ab initio calculations of wave functions for small atoms and molecules.

8. Microbiology (Professor D. M. Green)

The research accomplished by the support of NASA Research Grant NsG-416 from August 1964 to May 1965 has involved studies on the organization of genetic function in the DNA molecule of a Bacillus subtilis bacteriophage. This has been undertaken through simultaneous genetic and physical analysis of bacteriophage DNA molecules that have been broken into fragments of half and quarter molecules. Determination of the changes in the capacities of these smaller fragments to carry various pairs of genetic markers has been made and, thus, correlations between the genetic map (derived through recombination processes) and a physical map of the bacteriophage DNA molecule can be made.

In recent months extensive effort has been made to refine our procedures of characterization of the biologically active fragments. These studies have involved specific isolation of whole, half and quarter molecules through the use of the preparative and analytical ultracentrifuges. They have confirmed our original conclusions that sheared DNA retains biological activity and that marker separation can result from shearing of DNA. These studies enable accurate assessment of the intrinsic genetic potential of

sheared molecules unencumbered by the presence of contaminating unsheared molecules.

This program of research now receives major support from other sources.

9. Geophysics (Professor W. L. Pilant)

The determination of Rayleigh wave reflection coefficients for wedge angles greater than 180° has been completed. In general, these results confirm first order approximations which predict a phase shift antisymmetry for angles about 180°, i.e., the phase shift for 190° is the negative of that for 170°, etc. Numerical agreement is only fair however. An apparent anomaly exists at an angle of 210° where the phase shift is lower than expected: there is no explanation for this effect at the present time.

The largest part of the research program in the last six months was the analysis of Rayleigh surface waves from selected earthquakes at the North American stations of the Worldwide Standardized Seismic Network from the microfilmed records distributed by the U. S. Coast & Geodetic Survey. This part of the work is wholly sponsored by the Air Force Office of Scientific Research. This has involved the analysis of four events and some 62 individual records to date. A number of computer programs are under development to utilize this data for the determination of crustal structure under the North American Continent.

10. General Relativity (Professor A. H. Thompson and Mr. R. Reynolds)

The group whose work is here reported consists of Professor A. H. Thompson and one research student, Mr. R. Reynolds.

Mr. Reynolds has been concerned with generalizations of results obtained by Kerr and Schild (1) and Thompson (2) for space-times V_4 and $\bar{V}_4$ whose metric tensors g_{ab} and $\bar{g}_{ab}$ are related by

$$g_{ab} = \bar{g}_{ab} + k_a k_b$$

where k_a is a null vector-field of $\bar{V}_4$.

Shear-free Motion of a Fluid in Space-time--A time-like congruence U_a in space-time (signature +2) allows of the decomposition

$$U_{a;b} = \sigma_{ab} + \omega_{ab} + \tfrac{1}{3}\theta\,(g_{ab} + U_a U_b) - \dot{U}_a U_b,$$

in its first covariant derivative, where $\sigma_{ab} = \sigma_{ba}$, $g^{ab}\sigma_{ab} = 0$, $\omega_{ab} = -\omega_{ba}$ and $\dot{U}_a = U_{a;b}U^b$, with g_{ab} denoting the metric of space-time. Physically, the time-like congruence can be considered as the stream-lines of a fluid in space-time. The terms σ_{ab}, ω_{ab} and θ determine the shear (distortion), rotation and expansion of a fluid element, whilst $\dot{U}_a$ measures its absolute acceleration.

A method of considering the shear-free motion ($\sigma_{ab} = 0$) of a rotating ($\omega_{ab} \neq 0$) fluid (see §5 of the reporter's contribution to the last NASA report of this Institution) in terms of ANHOLONOMIC SUBSPACES V_4^3 of space-time has yielded additional results for the case of Rigid Motion (3), i.e., a shear-free, expansion-free ($\theta = 0$) time-like congruence. In particular the sufficient conditions for the validity of the Herglotz-Woerther Theorem (4) given in the literature (5) have been considerably weakened. This work is now being prepared for publication.

Additional work has also discussed space-times which satisfy the differential condition

$$R^a{}_{bcd;a} = 0$$

where R^{a}_{bcd} is the curvature tensor of space-time. For a detailed report see (6) and SRCC Report #22 of this Institution.

(1) R. Kerr and A. Schild: Report to the International Meeting on General Relativity - Florence, Italy, September, 1964.

(2) A. H. Thompson: Tensor (to appear shortly).

(3) F. A. E. Pirani and G. Williams: Séminare Janet 8-9, 1962, Paris.

(4) G. Herglotz: Ann. Phys., Leipzig 31, 393, 1910.

(5) R. H. Boyer: Proc. Roy. Soc. A. 283, 343-344, 1965.

(6) A. H. Thompson: Thesis, University of London, England, 1961-1962.

III. Project Reports--School of Engineering

Introduction

The School of Engineering has enjoyed the use of only a limited quantity of funds from NASA Grant NsG-416 during the 1963-1964-1965 academic years. The major development effort in the School of Engineering is now to begin. In the past, NASA funds have been allocated to Engineering for the support of activities in the Department of Metallurgical Engineering and in the Aero-Space Option of the Department of Mechanical Engineering. In the present academic year, NASA funds will play a major role in the initiation of research throughout most of the School. The following summarizes activities of this present year.

1. Chemical Engineering: "A Study of Methods for Determining Supersonic Jet Velocities of Polyatomic Gas Molecules Involving Delayed Equipartition of Rotational, Vibrational and Translational Energy."

The measurement of supersonic gas velocity of polyatomic molecules is difficult because of the delay in equilibrating the vibrational, rotational energy and translational energy. A unique experimental technique involving the compensation for windage, friction, and delayed equipartition has been devised using a partially driven velocity wheel.

The experimental equipment includes a vapor generator on expansion nozzle and a motor-driven velocity wheel mounted in a vapor condensing tank. The expanding vapor exiting from the nozzle impinges on the velocity wheel blades and is condensed. The bearing

friction of the velocity wheel and drive are measured by driving the wheel in vacuum. Windage compensation is determined by driving the wheel in stagnant vapor at the proper static temperature and pressure. Finally, the wheel speed is measured at full nozzle flows. The compensated wheel-speed with blade attack-angle corrections provides the true jet average velocities.

This study will make possible the simple pitot measurement of space vehicle reentry velocity and supersonic velocity of polyatomic gases in supersonic flow regimes by providing appropriate correction factors to standard techniques.

2. Civil Engineering: Funding received from the NASA grant for the year 1965-1966 is being used by the Civil Engineering Department to initiate research in two areas.

a. In the first area, the stress-strain behavior of particulate material in high pressure environments is being studied. Problems involving coupling of instruments to ocean bottom or recovery of space equipment require such information. A better understanding of the mechanism of stress transmission is needed to predict behavior of such materials in extraterrestrial environments. By testing and extending existing theories, new areas of research in the behavior of particulate material in extreme environments will be generated and evaluated.

b. A second project is designed to establish a stochastic model of motion of solid particles in a non-circular conduit, and simulate the model on a digital computer. The results will be compared with available experimental data and a deterministic model. Information and techniques of this type are important for a complete

understanding of sediment transport and dispersion, and, because of its basic nature, will lead to other research activities involving stochastic models of the motion of solid particles in various media. Examples include the motion of particles in our atmosphere and interplanetary space, and the motion of particles in a wind tunnel.

3. Electrical Engineering: "Adaptive System Studies."

The financial support for the project Adaptive System Studies will be mainly for salary support and equipment purchase. The studies are being developed along three coordinated directions: adaptive logic systems, adaptive control systems, and implementation of thin film devices for adaptive systems.

Four faculty members, Drs. Sze, Meiksin, Li and Jessep, will participate in the research project. In addition, three research assistants have been appointed; they are Messrs. Sha, Grabowski and Teng.

While the project will provide direct support to these personnel, it will also serve to seed the general growth of research within the Department and the School. The equipment purchased will be made available to those faculty and other graduate students interested in the research on adaptive systems study. In connection with this, a series of workshops and seminars have already been scheduled with the purpose of training the interested persons on the basic background of the project area. The response has been enthusiastic from the graduate students. It is our estimate that there will be as many as six full-time fellowship students that will participate in the project without financial support from the project. Note that this is in addition to the personnel supported by the project

and that this is in the area of adaptive logic systems alone. It is expected that the catalyst action of the project will be similar in the two other sub-areas. This catalyst action, in the short initial period of the project, has been the most significant achievement of the project.

Moneys allocated to this project will provide necessary facilities to carry on the research beyond the theoretical stage. The lack of equipment has always been a limitation to the research effort of the individuals involved and the Department. Provision of some basic equipment for experimentation will greatly extend our research capability.

We have reason to believe that the research findings from the project will not only stimulate more interest in this area, but also generate other sources of support. For example, the findings of adaptive threshold theory and learning systems should result in applications for support from other sources in pattern recognition and artificial intelligence. Work in thin film should find application in medical and biological fields. Possible support may come from other federal agencies and the service (military) agencies.

4. Industrial Engineering: "Analysis and Simulation Laboratory for Information Retrieval Systems."

The objective of this project is to create several files relating to recent and current literature in an area of research of interest to scientists everywhere, and specifically those engaged in the space effort. In general it is intended that these files be operative in parallel each with a somewhat different approach to the IR problem, each catering to a somewhat different population of users,

yet all operating in the same major area of interest where the same body of knowledge can be used for each.

For the sake of economy, these files will be obtained from presently operating systems such as MEDLARS, DDC, NASA, etc., in the area of Bioengineering. Once such files are created, programs will be written for file maintenance, analysis, and research. Graduate students can utilize this laboratory for their theses research and conduct various experiments on the files. The major effort, however, will be to design experiments and perform research not only to compare systems and their parameters but also to attempt to develop measures and useful criteria for evaluating IR systems in general.

In the beginning limited funds will be required for negotiating and creating the files. A larger effort will then create the necessary computer systems and/or programs for operating with the files. The preparation of the design of various experiments and the analysis of results will constitute the third major expenditure. After the initial results are obtained, other sources of funds will be approached to continue this research and expand its scope.

It is expected that this laboratory will provide a needed research facility to the Department of Industrial Engineering and will provide much needed information about effectiveness of IR systems so important to the total NASA effort.

5. Mechanical Engineering: "Analytical and Experimental Investigation of Anisotropic Shells Subject to Mechanico-Thermal Loading."

This research program is in the initial stages. The purpose of the proposed study is to investigate the behavior of laminated and reinforced shells of revolution subjected to mechanical-thermal

environments. Specific objectives of this research are: the development of analytical techniques to describe the behavior of such structures assuming they behave as a linear visco-elastic material with temperature-dependent properties, observation of buckling modes under various load conditions, relating post-buckling structural response to loading, establishment of methods for prediction of failure and static post-failure characteristics, to study the effect of various types of reinforcing on shell behavior, and to study the behavior of elastic-visco-elastic laminated shells.

The funds allocated are being used to purchase equipment and construct the experimental facility and for a limited amount of salary support. The test facility is a radiant heating chamber suitable for testing conical and hemispherical shell models under various combinations of heating rate and pressure loadings. It will be useful for extension of the present effort to other types of shell construction and other fundamental investigations in the area of thermoelasticity.

This research is important to the space effort as the types of structures and loadings under investigation are those involved in aerospace vehicle design and more accurate methods of analysis are required to achieve the desired minimum structural-weight fractions. The knowledge gained will also be useful in any industrial application where similar loadings and types of vessels may be involved. It augments the teaching efforts in the Department's general field of applied mechanics and its relationship to design, and the experimental facilities will provide a means for graduate students participating in this and future investigations to relate theory to the physical problem.

6. Metallurgical Engineering: The Metallurgical Engineering Department plans to spend its $10,000 allocation primarily as seed money on personnel to generate research ultimately related to the NASA space effort.

Two graduate student assistants currently are being recruited at the standard University stipend of $3,195 (for three trimesters) effective January 1, 1966. This will assist the Metallurgical Engineering Department in its effort of promoting the transition to greater full-time doctoral programs in contrast to its present overwhelming part-time graduate study program. These graduate students may elect to work in the fields of materials (space, biomedical, etc.) thermodynamics, liquid metals, x-ray crystallography and spectrography as well as the development and evaluation of engineering alloys for space applications.

The third segment of the allocation, $3,610, will be used to sponsor a young Ph.D. assistant professor's third trimester research (salary, materials, apparatus, etc.). Dr. Donald Dukelow has initiated requisitions for materials on his "kinetics of Oxidation of Molten Iron Alloys" program. These funds will provide the start of a research program in that area and generate opportunities for training of graduate and undergraduate students in this area.

Dr. E.I. Salkovitz is in the process of installing new equipment in his new laboratory located in the Space Research Coordination Center. Construction will be started in the very near future on the furnace, controls and auxiliary temperature control, and measuring apparatus necessary for his investigation of the properties of liquid metals. Postdoctoral candidates for study in this area have been screened. The candidate has been selected and negotiations are being started for this appointee.

7. Center for the Study of the Thermodynamic Properties of Materials:

a. Publications--During the past year the Proceedings for the Thermodynamics Conference which was held in November and December 1964 have been edited and corrected by all of the twenty lecturers who appeared on various panels. These papers together with the discussions which followed each panel presentation have been combined in a manuscript for the Conference Proceedings and a contract has been executed with the Gordon and Breach Company in New York City for its publication. Word has just been received that the manuscript is now currently at the printers in England and the galley proof will be received for final corrections shortly. The Proceedings will be published and marketed both as paperback and hardback volumes and should be available within the next several months.

There were three other papers which were presented for publication during the past year as follows:

1. "The Sampling and Analysis of Liquid Steel for Hydrogen and Oxygen," by C.D. Cassler and G.R. Fitterer, published by the Journal of Metals, June, 1965. Also reprinted in the National Open Hearth Proceedings 48, 137, 1965.

2. "Applications of Thermodynamics to High Temperature Metallurgical Processes," presented by G.R. Fitterer as a paper before the Annual Meeting of the Electrochemical Society in San Francisco, May, 1965 and submitted for publication in the Society's journal.

3. "Entropy, Lattice Parameters and the Melting Phenomenon," presented by G.R. Fitterer for publication in Acta Metallurgica.

Several other publications are in progress and will be reported later.

b. Research Projects

1. "Determination of the Phase Boundaries in the System Co - Pt." R.J. King

Mr. King had initially attempted to determine the thermodynamic properties of these alloys through the use of a double electrolytic cell which involved a ZrO_2 - CaO solid electrolyte. Difficulty was encountered in obtaining stable relationships between the two half-cells. A new technique which has been developed by Dr. Schmalzried uses merely a half-cell with the same solid electrolyte. This has been used with an appreciable degree of success. It is now clear that Mr. King will be able to complete this work in the near future and in so doing will have prepared others to continue research of this type. Information obtained from this investigation enables one to calculate the phase boundaries in a binary alloy ststem at high temperatures in the neighborhood of 1000 to 1200°C.

2. "Differential Thermal Analysis in the System Nb - Zr." C.J. Kubit

This project is also a high temperature investigation which involves the study of various alloys across the Niobium - Zirconium system by a method which was developed by C. Smith at the Institute of Metals, University of Chicago. Some difficulties have been encountered in the development of this unit because the experimental temperatures being studied are beyond the limits of any previous investigation. A sufficient number of the difficulties have been analyzed so that it is now believed that a redesign of one portion of the unit will permit the determination of heat contents of these various alloys above 1000°C. From this information, integral thermodynamic data will be obtained from which it is hoped that the phase boundaries in this system may be determined.

3. "Development of a Levitation Melting-Drop Calorimeter." D.W. Blewitt

A 10 KW high frequency generator was given to the Center by the Westinghouse Corporation and this has been converted for levitation melting of the various alloy systems of interest. This unit is already in operation for levitation melting and currently is being designed so as to incorporate a calorimeter which is positioned just below the melting unit. The liquid alloys may then be dropped directly into the calorimeter without a change of atmospheric conditions. This is perhaps the first calorimeter of its type in existence.

One of the problems involved the measurement of the temperature of the levitated liquid globule and this has been solved through the use of the Milletron, Double-Wavelength, Optical Pyrometer which eliminates the need for knowing the emissivity correction factor.

The calorimeter will be calibrated against known heat values and after its characteristics are determined, the unit will be used for the determination of heat contents of alloys.

The advantages of this equipment for high temperature purposes is quite obvious. The metals under consideration are very reactive and will attack any refractory crucible in which they are melted. However, by levitation melting no crucible is needed. In addition, the melting can be carried out under low pressure - inert gas conditions so that reaction with the gases, oxygen, nitrogen and hydrogen can be avoided.

4. "Development of Vacuum Vapor Plating Techniques Similating Binary Systems." Dr. A.R. Freda and A.H. Hartswick

Equipment has been purchased and placed in operation for the counter-plating of wedges of pure materials, one superimposed upon the other. This is done in such a manner so that the combined layers

constitute a complete phase diagram from 100 per cent of one metal on the one side to 100 per cent of the other metal on the opposite side. Already, such systems as niobium-chromium have been prepared in this manner. The temperature encountered in this system is as high as 2410°C which is the melting point of niobium.

5. "Effect of the Formation of a Chromium Spinel on Refining Reactions in the Acid Open Hearth Furnace." M. Tubino (Dougherty Foundation Scholar)

This project involves experiments which are being conducted directly in the steel plants on commercial heats. The solution of the problem has required the use of thermodynamic calculations to explain some of the various reactions which occur in the acid open hearth. Under certain conditions, a spinel ($FeO - Cr_2O_3$) is formed in the slag and this has seemed to prevent the diffusion of iron oxide from the slag to the metal as in the normal refining procedure. This particular spinel has been identified by various methods including the use of a Laser Microprobe at the Harbison-Walker Research Laboratories. It is believed that sufficient knowledge is now available regarding the behaviorism of this and other spinels so that special refining procedures can eliminate any difficulty in the manufacturing process. Mr. Tubino should be able to complete this work as his M.S. thesis in the near future.

Summary

It is evident from the above that the NASA grant will play a major role for this and the next several years in the School of Engineering at this institution. It will permit the initiation of research in some departments while in others it will sponsor new directions for already proved research capabilities. The following is

conservatively estimated to be representative of our involvement in space-related, NASA sponsored research by the end of the 1965-1966 academic year:

	Number of Faculty	Number of Students
Chemical Engineering	2	3
Civil Engineering	2	2
Electrical Engineering	5	5
(Note: These will be distributed through two major projects directly under NASA sponsorship. Four other space-related research projects will hopefully be supported from other funds.)		
Industrial Engineering	3	6
Mechanical Engineering	12	15
(Note: The 15 students listed include 3 undergraduates. The faculty and students are in both the mechanical and the aerospace options of this department.)		

Although the Metallurgical Engineering Department is not listed above, it is difficult to exclude any phase of the effort in that effort whereas the above listing includes only those projects which have a particularly space-related character.

While it is apparent that publications in this broad general field have not yet begun to appear in large numbers, some evidence of the interest and involvement of the faculty is already apparent. Thus, for example, the following exemplify these interests:

1. "Uplifts - University of Pittsburgh Linear File Tandem System," Communications of the ACM, September, 1965 by J.D. Canter and C.E. Donaghey.

2. Thesis
"A Comparison of Keyword-In-Context (KWIC) Indexing to Manual Indexing," Richard L. Binford, August, 1965.

3. Thesis
"TFL Automatic Indexing System: Discussion and Empirical Results," Jay F. Nunamaker, August, 1965.

4. "Sudden Contraction Losses in Two-Phase Flow," Transactions of the ASME, Journal of Heat Transfer, Gene E. Geiger with Wesley M. Rohrer, 1966.

5. "Sudden Contraction Losses in Two-Phase Flow," ASME and AIChE Heat Transfer Conference, Los Angeles, August 8-11, 1965, Gene E. Geiger with Wesley M. Rohrer.

6. "Further Studies in the Standardization of Testing Methods in Wound Healing," White, Walker, Marangoni, and Glaser. Presented at the Plastic Surgery Research Conference, Philadelphia, April, 1965.

7. "Solution of the Equations of Elasticity for Homogeneous and Nonhomogeneous Finite Elastic Bodies by Means of Finite Integral Transforms and Calculus of Variations," Ph.D. Dissertation, Alan A. Glaser, University of Pittsburgh, 1965.

8. "Burnout in Steam-Water Flows with Axially Non-uniform Heat Flux," Wesley M. Rohrer with O.G. Smith and L.S. Tong, Winter Annual Meeting, ASME, Chicago, Illinois, November 7-11, 1965.

It is expected that these interests will both broaden and increase in number under the stimulus of the NASA grant.

IV. NASA Predoctoral Trainees

Name	B.S./B.A. From	Year	Department	QPA Undergraduate	QPA Graduate
William P. Coffman	Thiel College	1963	Biology	3.15	3.87
Anthony Sobota	Indiana State College	1960	Botany	3.10	3.90
Rochelle B. Abrams	University of Pittsburgh	1962	Chemistry	3.78	3.69
Philip H. Harju	The N. Dakota Agricultural College	1956	Chemistry	2.37	3.31
Nancy Heatwole	Madison College	1959	Chemistry	3.80	3.70
Charles Springer	Swarthmore College	1962	Chemistry	2.10	3.72
Charles R. Seeger	Ohio State University	1953	EPS*	2.64	3.53
Nunzio A. Tartaglia	Manhattan College	1958	EPS	3.91	3.85
Paul Demmie	University of Pittsburgh	1964	Physics	3.51	3.41
George A. Doschek	University of Pittsburgh	1963	Physics	3.70	3.91
David Emin	Florida State University	1962	Physics	2.76	3.46
Richard Hake, Jr.	California Institute of Tech.	1964	Physics	3.20	4.00
Robert L. Nielsen	Pennsylvania State University	1962	Physics	3.27	3.11
Brian K. Thomas	Reed College	1965	Physics	3.20	3.50
Raymond Turner	Carnegie Institute of Technology	1960	Physics	3.07	3.28
David L. Uhrich	Canisius College	1960	Physics	3.63	3.57
Charles S. Weller	Massachusetts Institute of Tech.	1962	Physics	2.00	3.16

*Earth and Planetary Sciences

Name	B.S./B.A. From	Year	Department	QPA Undergraduate	QPA Graduate
Joseph A. Zelik	University of Pittsburgh	1963	Physics	3.55	3.43
Donald E. Stabell	Canisius College	1963	Physics	3.30	3.38
John M. Lyons	Loyola University, Chicago	1962	Psychology	3.41	3.60
James W. McKearney	C.W. Post Coll. of Long Island U.	1962	Psychology	3.79	4.00
George Delancey	University of Pittsburgh	1962	Chem. Eng.	3.10	3.75
Patrick Kokoska	University of Pittsburgh	1965	Chem. Eng.	3.37	3.25
Edward J. Nemeth	University of Pittsburgh	1960	Chem. Eng.	3.31	4.00
Edward M. Phillips	Layfayette University	1958	Chem. Eng.	3.15	3.50
William G. Abkemeier	St. Louis University	1962	Elec. Eng.	3.52	4.00
Marshall Abrams	Carnegie Institute of Technology	1962	Elec. Eng.	3.16	3.00
Bruce Fike	Union College	1965	Elec. Eng.	3.69	3.50
Leo C. Geary	University of Pittsburgh	1964	Elec. Eng.	3.42	4.00
William Gregor	Layfayette College	1963	Elec. Eng.	3.58	4.00
Paul A. Kossey	University of Pittsburgh	1960	Elec. Eng.	3.66	3.00
William L. Montgomery	Lehigh University	1963	Elec. Eng.	3.00	3.75
George Mosteller	University of Pittsburgh	1963	Elec. Eng.	3.30	3.75
David C. Opferman	Pennsylvania State University	1961	Elec. Eng.	3.40	
Ronald Coffield	University of Pittsburgh	1965	Mech. Eng.	3.59	3.50
William T. Mason	University of Pittsburgh	1963	Mech. Eng.	3.42	3.33
Robert L. Powell	University of Cincinnati	1957	Pharmacy	3.28	3.74
Dennis W. Whitson	N. Dakota State University	1961	Physics	3.30	3.67

V. SRCC Reports

These reports, issued in special covers, are selected preprints or reprints of research done by SRCC staff members. The reports are circulated to space-oriented laboratories in this country and abroad.

No.	Title	Author	Date
1	Selected Reprints in Upper Atmosphere Physics and Laboratory Astrophysics	Various	15 October 1965
2	Rocket Measurements of the Visible Dayglow	E. C. Zipf, Jr.	23 April 1965
3	Low Energy Electron-Atom and Electron-Molecule Scattering Theory Circa 1964	E. Gerjuoy	10 May 1965
4	Momentum Transfer Theorem for Inelastic Processes	E. Gerjuoy	10 May 1965
5	Ionospheric Reaction Rates in the Light of Recent Measurements in the Ionosphere and the Laboratory	T. M. Donahue	27 May 1965
6	The Hydrogen Lyman α Airglow	T. M. Donahue	27 May 1965
7	Some Considerations Concerning Radiation Transport in the OI 1304 Triplet in the Upper Atmosphere	T. M. Donahue	27 May 1965
8	The Sodium Airglow	T. M. Donahue	27 May 1965
9	Multiple-Wave Propagation and Causality	E. Gerjuoy	27 May 1965
10	Flow Separation and Reattachment in an Unequal Elbow	R. K. Duggins	15 July 1965
11	Ionospheric Reaction Rates in the Light of Recent Measurements in the Ionosphere and the Laboratory - II	T. M. Donahue	5 August 1965

No.	Title	Author	Date
12	The Effect of Lateral Flow on Exospheric Densities	J. R. McAfee	15 September 1965
13	Optical Studies of Electron and Hole Trapping Levels in Quartz	M. Schlesinger	8 October 1965
14	The Runge-Lenz Vector and the Coulomb Green's Function	L. Hostler	10 October 1965
15	The Problem of Atomic Hydrogen	T. M. Donahue	11 October 1965
16	Projective-Symmetric Spaces	R. F. Reynolds A. H. Thompson	22 October 1965
17	A Class of Related Space-Times	A. H. Thompson	29 October 1965
18	An Interpretation of a Far Ultraviolet Dayglow Experiment	T. M. Donahue	15 October 1965
19	Detection of High Altitude Explosions by Observation of Air Fluorescence	T. M. Donahue	4 November 1965
20	Reprints on Meteoritices, Selenology, and Hypervelocity-Impact Studies	Various	10 November 1965
21	Communication by Electrical Stimulation of the Skin	R. H. Gibson	17 November 1965
22	A Note on the Petrov Types of Certain Space-Times	A. H. Thompson	8 December 1965
23	On the Ionospheric Conditions in the D Region and Lower E Region	T. M. Donahue	20 December 1965
24	Formal Scattering Theory and the Coulomb Problem	L. Hostler	27 December 1965